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**CALCULATIONS WITH UNC-SAM-2  
OF EXPOSURE RATES MEASURED IN AN OPEN BASEMENT**

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JULY 1968

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CALCULATIONS WITH UNC-SAM-2 OF  
EXPOSURE RATES MEASURED IN AN OPEN BASEMENT

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US ARMY  
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## ABSTRACT

A number of experimental studies are being conducted to validate theoretical methods of calculating fallout protection afforded by structures. As a part of this program, exposure rates in an open basement were measured at the US Army Nuclear Defense Laboratory (USANDL). This report presents calculated exposure rates for forty-eight detectors located within the open basement. These results were obtained using UNC-SAM-2, a Monte Carlo radiation transport digital computer code. The calculated results are compared with experimental measurements and also with comparable adjoint (Monte Carlo) results.

## FOREWORD

It is a pleasure to acknowledge the contributions of Dr. L. M. Petrie for his initial work with the UNC-SAM-2 code and Mr. A. T. Futterer for his assistance and continued interest in this work.

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CALCULATIONS WITH UNC-SAM-2 OF  
EXPOSURE RATES MEASURED IN AN OPEN BASEMENT

1. BACKGROUND

The US Army Nuclear Defense Laboratory (USANDL) has conducted experiments to determine the shielding afforded by open and concrete-covered basements (References 1 and 2). The theoretical methods set forth by Spencer (Reference 3) and the engineering methods presented by Eisenhower (References 4 and 5) were used by USANDL to calculate protection factors for both these experiments.

This report presents an effort to calculate theoretically the exposure rates for the open basement experiment (Reference 1) using Monte Carlo techniques.

This approach is necessary in order to isolate certain factors of fallout protection which are not amenable to direct experimental verification.

The Monte Carlo method is best suited for the calculation of fallout protection afforded by structures for two reasons. First, more complex geometries can be represented via Monte Carlo than by other methods. Second, factors associated with the engineering methods, such as exposure contributions due to skyshine, in and down, etc., are easily separated in Monte Carlo calculations by placing infinite absorption cross

sections in certain volumes and allowing only certain desired contributions. The major difficulty associated with the fallout problem is the very large magnitude of the ratio of source to detection area. One suggested solution to this problem is the use of an adjoint Monte Carlo method in which particles are traced backward from detector to source.

The present report treats preliminary work done in the Theoretical Physics Branch of USANDL and is concerned exclusively with the open-basement program. A Monte Carlo code, UNC-SAM-2 (Reference 6) was used to calculate exposure rates for forty-eight detectors in the open basement. These exposure rates are compared with experimental results and with adjoint Monte Carlo calculations from the GADJET code (Reference 7).

Preliminary calculations are being performed for the closed basement problem, and the results will soon be forthcoming. Further work will be proposed to make the open and closed basement calculations for better accuracies and also to isolate the sources of the various components of the exposure rate for validation or modification of the engineering methods.

## 2. EXPERIMENT

Exposure rates were measured at USANDL (Reference 1) in the open basement shown in Figure 2.1. Beginning 1 foot below the top of the structure, detectors were spaced vertically

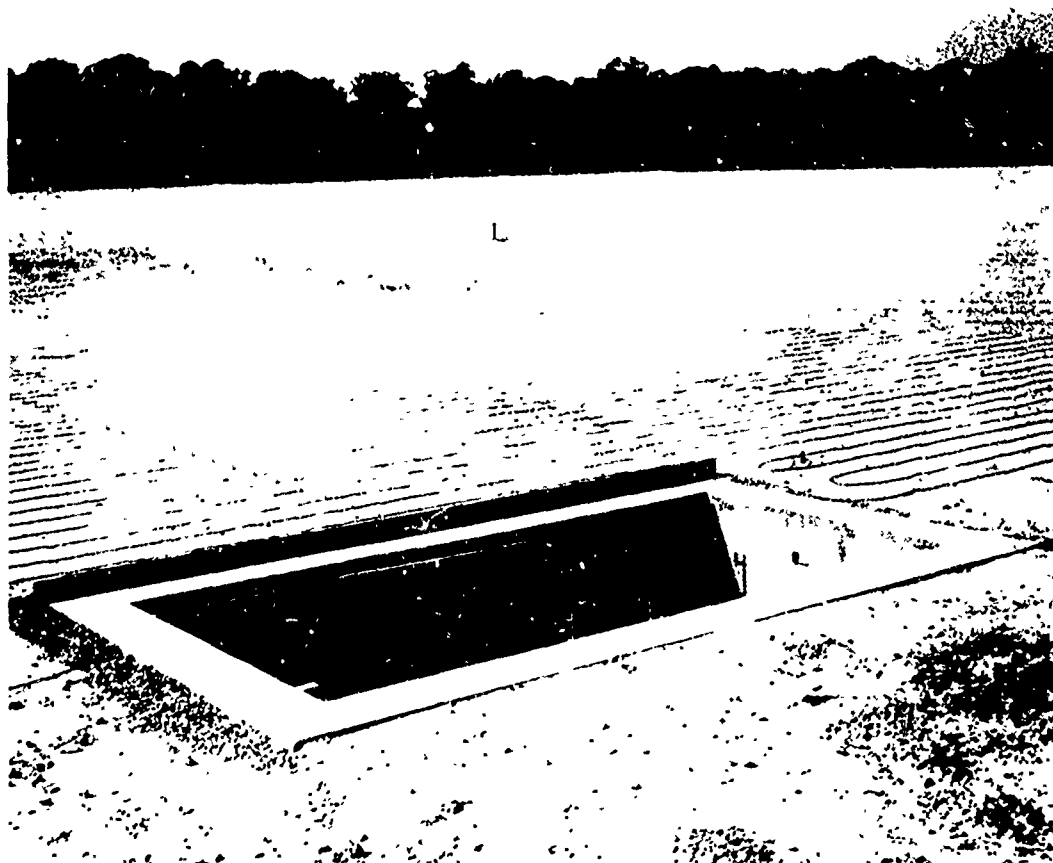


Figure 2.1 Layout of the basement and fallout field.

1 foot apart in banks of six (Figures 2.2 and 2.3). Forty-eight detectors were located in banks at positions A, B, C, D, E,  $a_2$ ,  $b_2$ , and  $e_2$  as indicated in Figure 2.4. A  $^{60}\text{Co}$  source was circulated within the tubing seen in the background of Figure 2.1. The tubing was laid in a semicircular configuration on the  $180^\circ$  flat field adjacent to the basement. The experiment was run for several annular radii; however, the present calculations are for a source radius of 60 feet (References 1 and 3). Also, for calculation purposes, it is assumed that the source is uniformly distributed ( $1 \text{ Ci ft}^{-2}$ ).



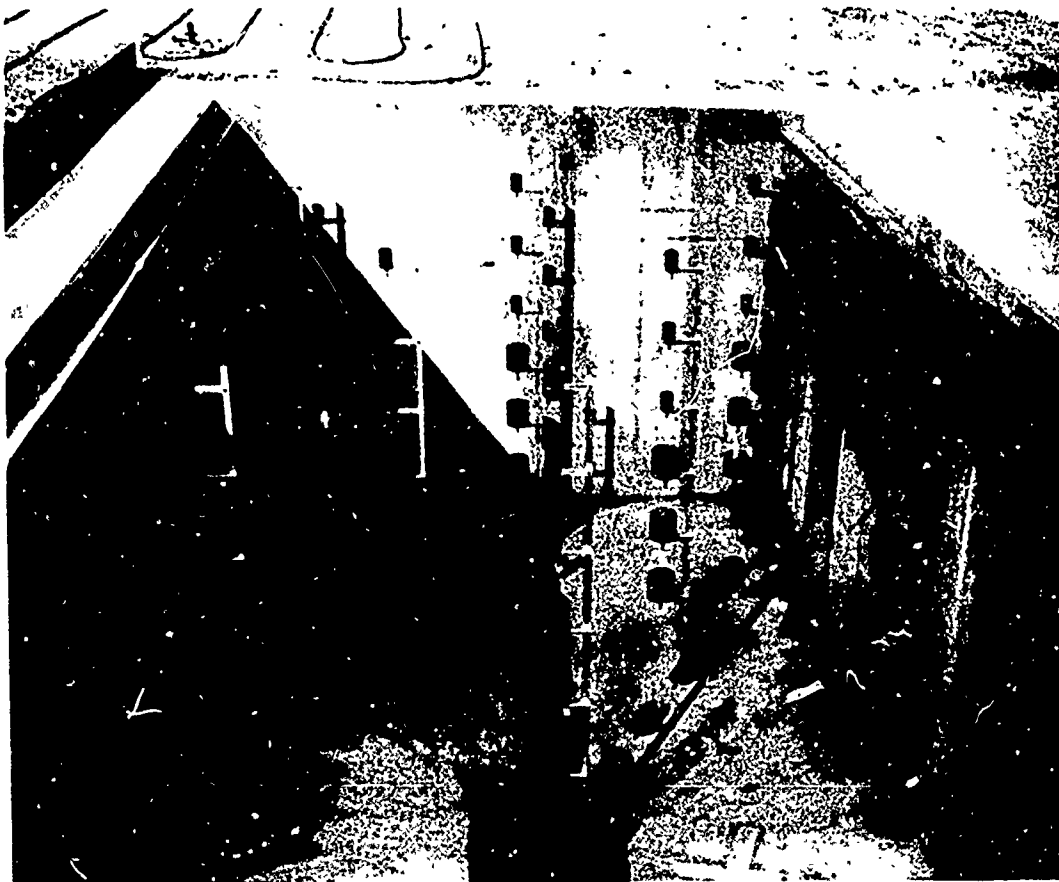


Figure 2.2 Detector positions in the basement.

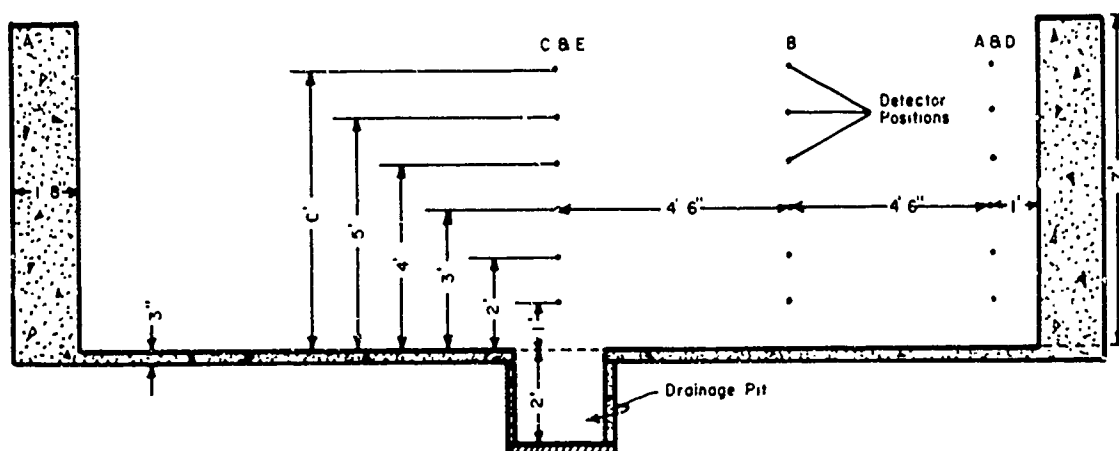


Figure 2.3 Cross-sectional view of the basement.

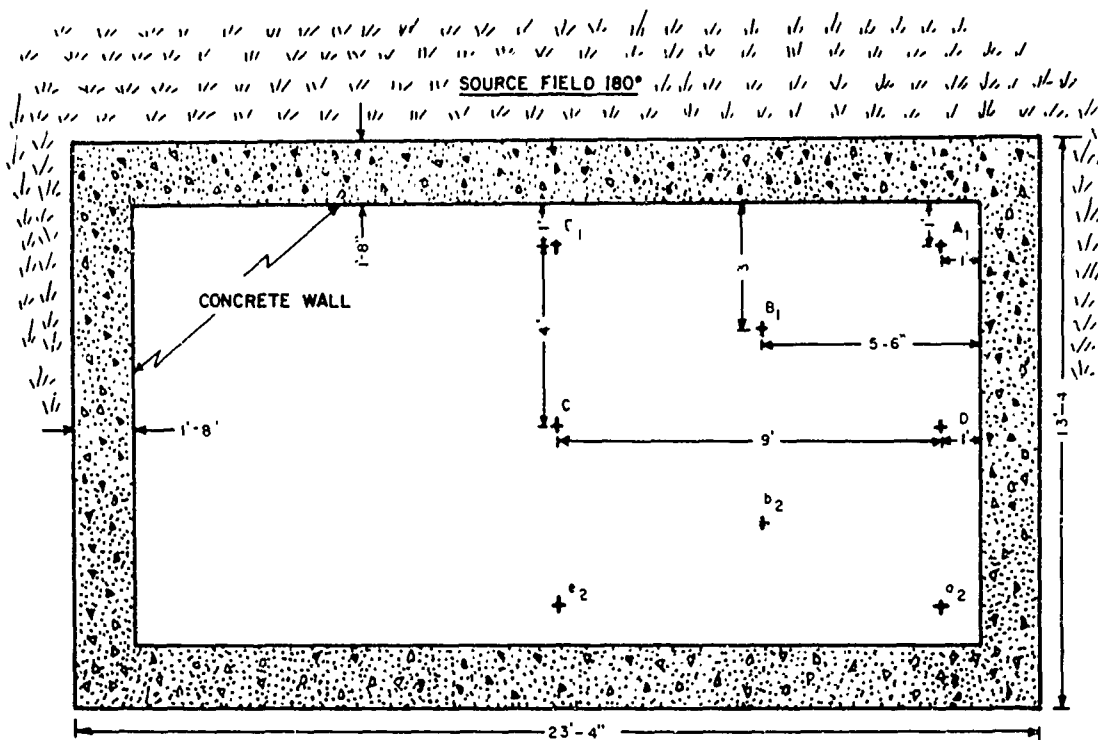


Figure 2.4 Top view of the basement showing primary and image detector locations.

This experiment was chosen as a test for the calculational method because of its simple geometry, accessible experimental results and available adjoint (GADJET) calculated results (Reference 7). Little difficulty would be encountered in performing similar calculations for other structures if the geometries were relatively simple and cross sections were available.

### 3. CALCULATIONAL METHOD

The Stochastic Approximation Method (SAM) developed by United Nuclear Corporation is well documented (Reference 6) and will not be discussed here in detail. Only the SAM information required to calculate the open basement results will be included in this report.

The salient specifications for UNC-SAM-2 are:

- (1) Source: Isotropic  $^{60}\text{Co}$  emitters were uniformly distributed in a thin air layer ( $10^{-5}$  cm) at the air-ground interface. The source energy peaks were 1.17 and 1.33 MeV.
- (2) Transport: The interactions allowed were Compton scattering and absorption by photoelectric and pair production processes.
- (3) Detection: Point detectors and the Flux at a Point (FAP) technique were used. The lower energy cutoff of these detectors was 20 keV.

The geometry setup for the basement is a straightforward assembly of thirty-three geometric regions. For example, each wall of the basement was represented by a concrete box with the appropriate dimensions; the atmosphere consisted of several large boxes, etc. Point detectors were placed at the appropriate coordinates within the basement region.

The fifteen energy groups shown in Table 3.1 were used throughout the computations.

TABLE 3.1 ENERGY GROUP STRUCTURE

Group	Energy (MeV)	Group	Energy (MeV)
1	1.35 - 1.25	9	.60 - .50
2	1.25 - 1.15	10	.50 - .40
3	1.15 - 1.05	11	.40 - .30
4	1.05 - 1.00	12	.30 - .20
5	1.00 - .90	13	.20 - .10
6	.90 - .80	14	.10 - .05
7	.80 - .70	15	.05 - .02
8	.70 - .60		

Both regional and angular weighting schemes were used in an effort to reduce the variance. These were established in such a way as to give photons moving towards the open basement more importance than the photons moving away from the basement. However, in this initial calculation, no effort was made to optimize the weighting scheme.

As indicated, Flux At a Point (FAP) technique (Reference 9) was used for the energy dependent detector flux calculation. Flux values were also determined for certain physical regions.

Subroutine SCR was written to calculate flux to exposure as follows:

$$D(E) = \beta H(E) E \mu_a(E) \psi(E) \Delta E \quad (R \ h^{-1})$$

$$D_{total} = \sum_{all \ \Delta E} D(E)$$

where:

$\beta$  = constant

$H(E)$  = detector response function

$E$  = average energy per energy group, (MeV)

$\mu_a(E)$  = air absorption cross section ( $cm^2$ )

$\psi(E)$  = particle track length per  $cm^3$  per  $E$  per initial particle

$\Delta E$  = group width (MeV).

$H(E)$  for the Victoreen detectors is shown in Figure 3.1 (Reference 8).

To obtain the total exposure from a  $360^\circ$  fallout field, exposure rates were calculated for three detector banks located at positions  $a_1$ ,  $b_1$ , and  $c_1$  (Figure 2.4). The exposure rates calculated for the  $180^\circ$  fallout field at positions C and D are doubled to obtain the exposure rates for the  $360^\circ$  field. However, due to nonsymmetry, the exposure rates for a  $360^\circ$  fallout field at positions A, B, and E, are obtained by adding doses calculated for the  $180^\circ$  field as follows:

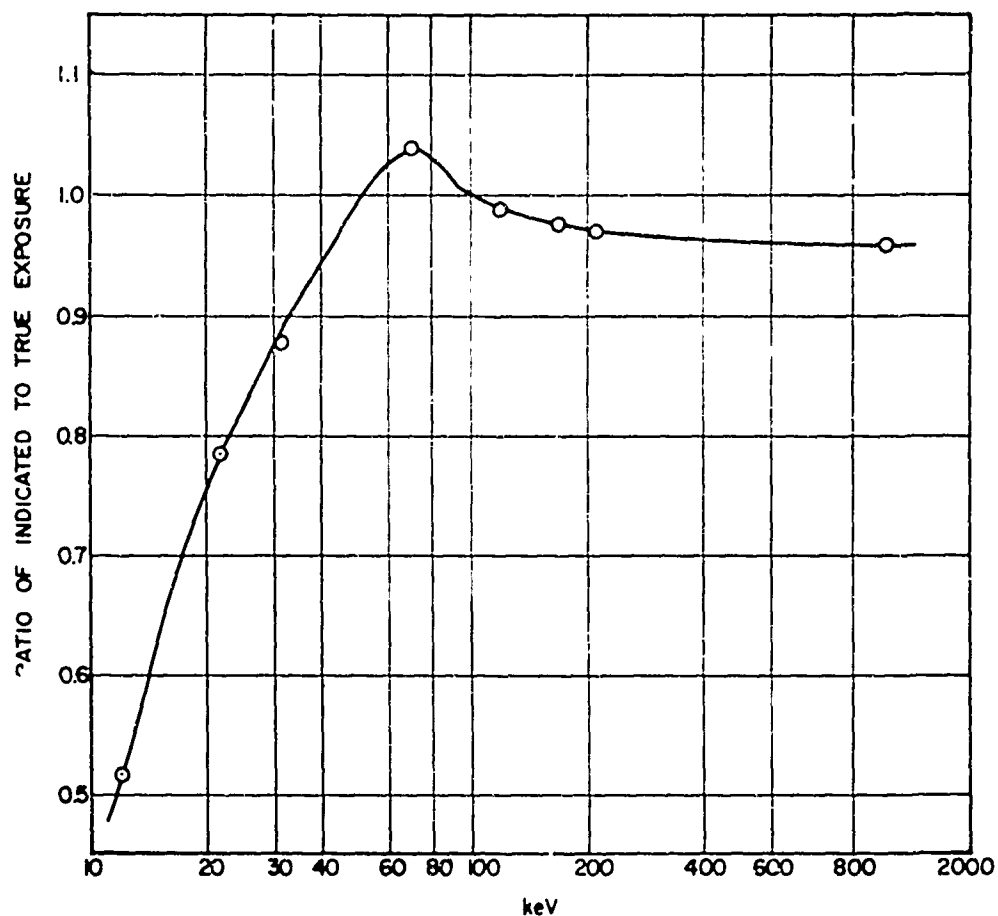


Figure 3.1 Energy response curve for Victoreen H(E) detectors (Reference 8).

$$A(360^\circ) = A_1(180^\circ) + a_2(180^\circ)$$

$$B(360^\circ) = B_1(180^\circ) + b_2(180^\circ)$$

$$E(360^\circ) = E_1(180^\circ) + e_2(180^\circ)$$

The GADJET method as well as the GADJET results presented here are well documented (Reference 7); suffice it to say that the GADJET code is based on solving the adjoint Boltzmann transport equation. The code traces particles from the detector to the source. All photons for which calculations are performed contribute to the final result.

#### 4. RESULTS AND COMPARISON

The experimental, calculated, and GADJET exposure rates are given in Table 4.1 for each of the thirty detectors located in banks of six each at positions  $A_1$ ,  $B_1$ , C, D, and  $E_1$  in Figure 2.4. These results are plotted versus height above the basement floor in Figures 4.1 through 4.5 for these positions.

Except for the detectors near the top surface, the UNC-SAM-2 results are in agreement with the experimental results. Note that experimentally determined exposure rates for the detectors near the top of the basement are considerably higher than those calculated by either UNC-SAM or GADJET.

The calculated standard deviation for the SAM results is approximately 30 percent for a given detector. Only region-angle weighting schemes were used in this initial investigation, and no optimum biasing schemes were used.

This work has shown that UNC-SAM-2 can be used effectively for fallout shielding calculations. The statistical accuracy could be improved by increasing the number of histories or with the use of more effective biasing. Further work will be done to isolate the sources of the various components of the exposure rate for validation or modification of the engineering method.

TABLE 4.1 COMPARISON OF EXPOSURE RATES OF DETECTORS AT VARIOUS LOCATIONS IN AN OPEN CONCRETE BASEMENT

Note: Exposure rates are in  $\text{mR h}^{-1}$ .  
For detector locations, see Figures 2.3 and 2.4.

Detector Height Above Floor (ft)	Exposure Rates					
	Experi- mental	Calcu- lated (SAM)	Adjoint (GADJET)	Experi- mental	Calcu- lated (SAM)	Adjoint (GADJET)
Detector Location A			Detector Location B			
1	666	651	464	880	759	838
2	781	708	304	1050	909	892
3	826	1244	537	1240	1539	1013
4	1010	1121	890	1450	1375	1419
5	1320	1949	1470	1960	2260	2057
6	2340	2208	1665	3360	2995	2345
Detector Location C			Detector Location D			
1	950	682	879	754	780	509
2	1090	1560	949	920	1092	500
3	1320	1717	1311	992	1170	764
4	1560	2030	1219	1170	1092	743
5	2000	2557	1785	1700	1873	1368
6	3900	3016	2488	2820	2341	2175
Detector Location E						
1	864	760	777			
2	976	846	767			
3	1160	1215	902			
4	1310	1216	1448			
5	1750	1661	1823			
6	3700	1981	1482			



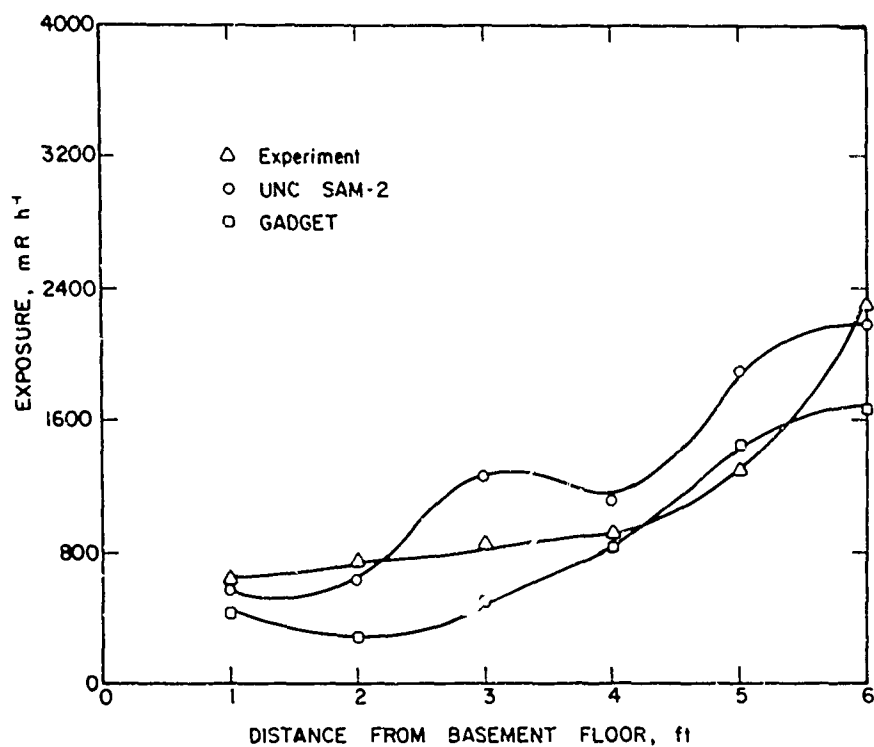


Figure 4.1 Exposure rates for detectors at position A in an open basement.

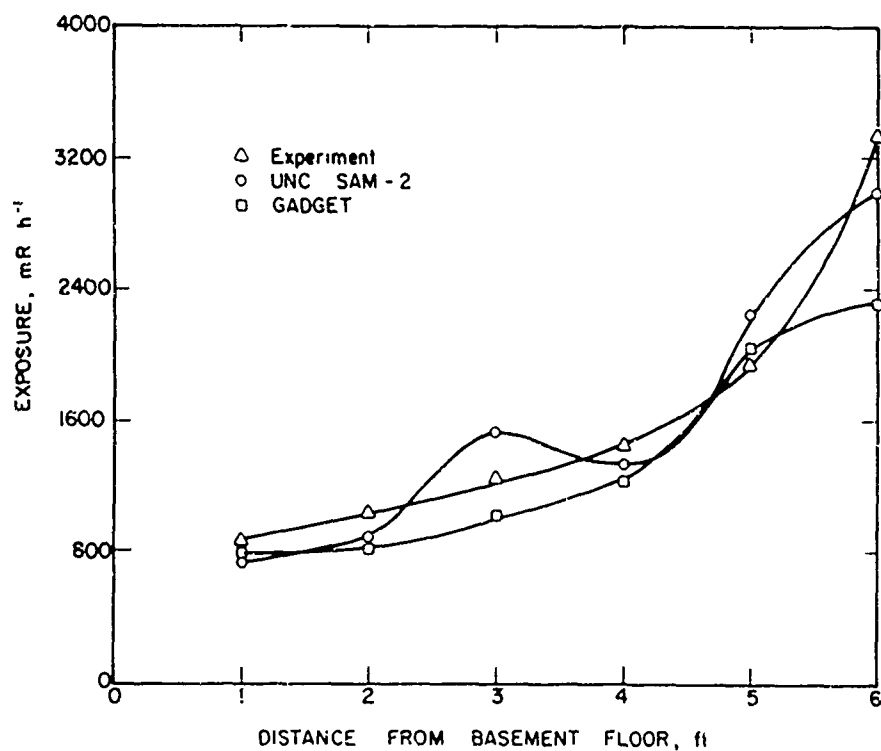


Figure 4.2 Exposure rates for detectors at position B in an open basement.

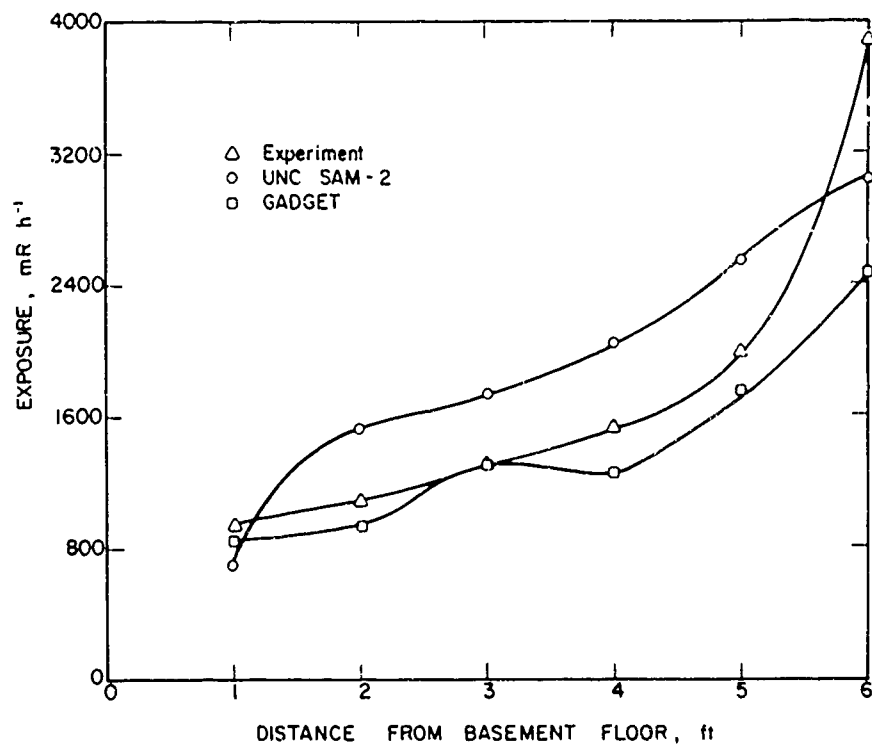


Figure 4.3 Exposure rates for detectors at position C in an open basement.

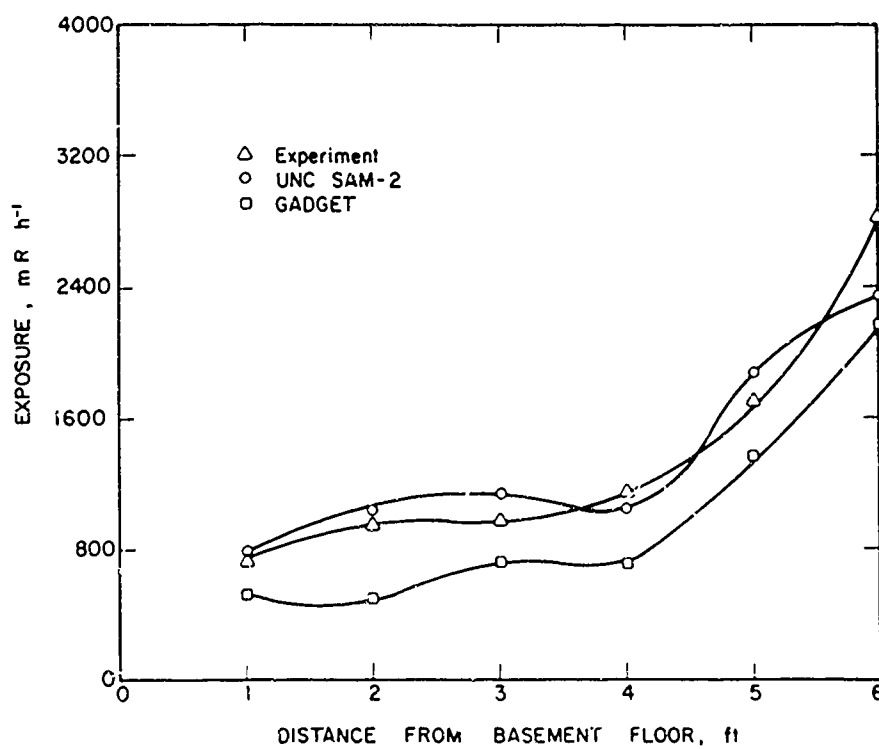


Figure 4.4 Exposure rates for detectors at position D in an open basement.

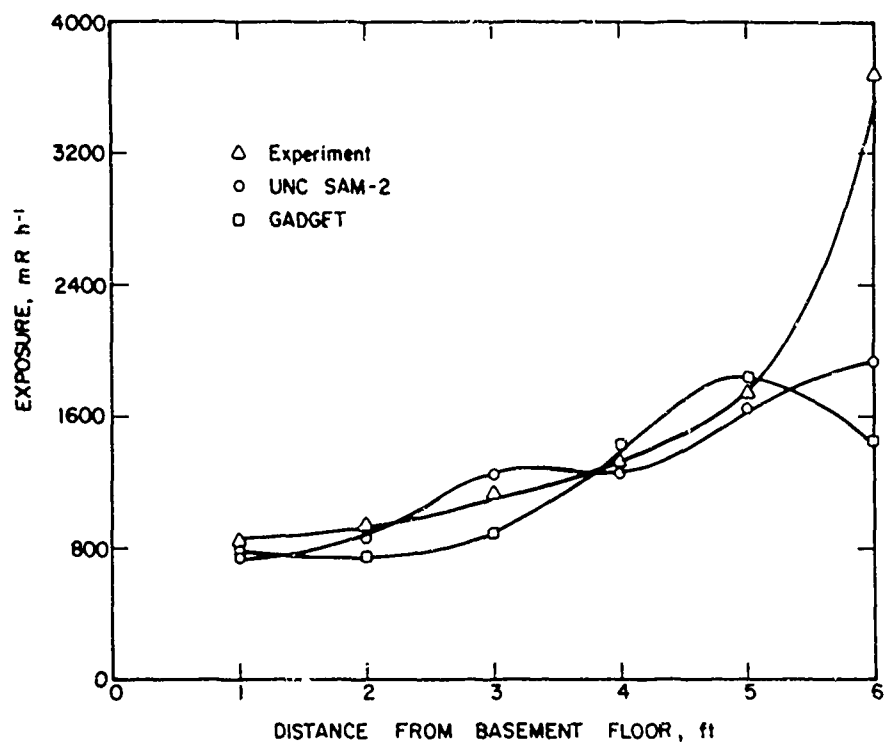


Figure 4.5 Exposure rates for detectors at position E in an open basement.

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